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Acquiring Data for the Development of a Finite Element Model of an Airgun Launch Environment

by Edward A. Szymanski

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14. ABSTRACT
The objective was to obtain both strain data (ue) and acceleration data (g) of a test article to aid in the development of a finite element model of an airgun launch environment. A 4-in airgun was utilized to obtain the required data from the test article. The author's responsibility for these series of airgun tests was to instrument the test article, configure and calibrate the on-board recorder, and retrieve and process the acquired data from each of the three airgun tests.

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Acknowledgments

For these series of tests, Ara Abrahamian of the U.S. Army Research Laboratory's Weapons and Material Research Directorate designed the aluminum cylindrical on-board recorder (OBR) housing and the test article/OBR housing end cap.

Mr. Abrahamian also conducted the three 4-in airgun tests to obtain the required data for finite element modeling of an airgun launch environment and also performed the analysis of the acquired data.

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1. Introduction

In order to acquire data from the development of a finite element model of airgun launch environment, the author utilized a 4-channel on-board recorder (OBR) which was configured to obtain and capture the required microstrain (ue) data, and the acceleration (g) data from the test article during a series of three, 4-in airgun tests. During these tests, the OBR was inserted into the OBR housing and was tightly packed with glass beads. The glass beads provided mechanical isolation for the OBR during the airgun tests. Instrumentation for these tests consisted of the usage of two each 60-kg piezoresistive accelerometers and the bonding of two "pairs" of uniaxial strain gages. Each pair of uniaxial strain gages was configured so as to measure both tension and compression microstrain responses of the test article, a cantilever beam. During the actual tests, only one pair of strain gages was utilized. The other pair of strain gages was to serve only as a backup, in case of damage to the first pair. During the third airgun test, the acceleration level was ~26.3 kg, and the microstrain level was ~3169 ue.

2. Test Article/OBR Housing End Cap

Figure 1 shows the top view of the test article/OBR housing end cap. The assembly is machined from one piece of aluminum stock. At the center is a cantilever beam; this is the "test article" portion of the OBR housing end cap. Note that one of the two 60-kg piezoresistive accelerometers is mounted on the end of the cantilever beam; the other 60-kg piezoresistive accelerometer is mounted on the top base of the OBR housing end cap.

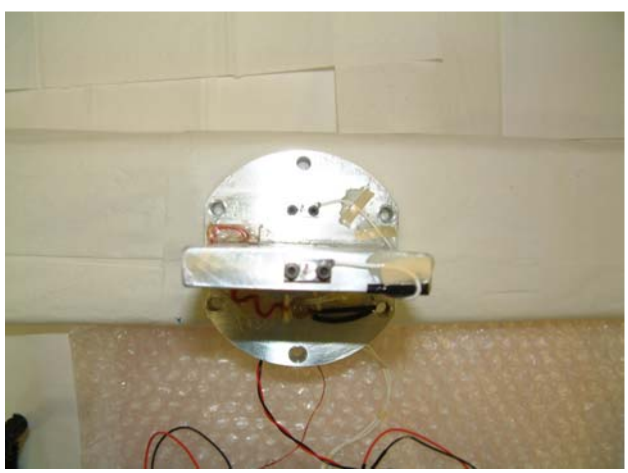

Figure 1. Top view of test article/OBR housing end cap.

3. Side View of the Test Article Showing Strain Gage Locations

To measure the tension and compression microstrain responses of the cantilever beam during the three airgun tests, two strain gage pairs of single axis strain gages were bonded to the test article, the cantilever beam.

For each strain gage pair, one single axis strange gage was placed on one side of the cantilever beam, and the other single axis strain gage of that strain gage pair was placed on the opposite side of the cantilever beam, in direct alignment to the first gage's position on the cantilever beam. Thus, the strain gage pair could measure both tension and compression of the cantilever beam.

Figure 2 shows the side view of the test article/OBR housing end cap. From this view, only one-half of the two strain gage pairs is visible. Hidden from this view, on the back side of the cantilever beam, are the other halves of the two strain gage pairs.

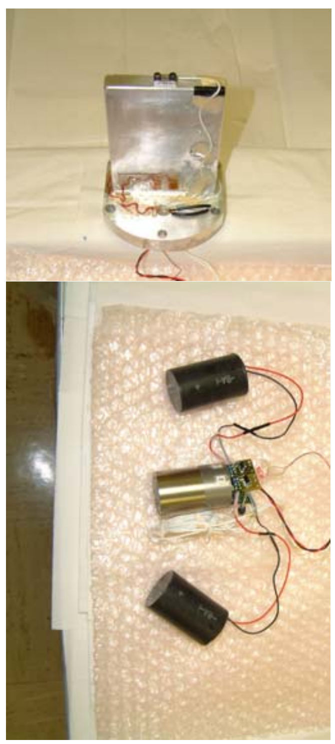

Figure 2. Side view of test article/OBR housing end cap.

All four single axis strain gages were bonded vertically (at maximum ue response orientation) and were positioned 1/8 in above the juncture of the cantilever beam and the OBR housing end cap. Horizontally, the gages were near the center line of the OBR housing end cap.

4. Surface Preparation of the Strain Gage Areas and Bonding of the Strain Gages

The normal laboratory-quality techniques utilized for surface preparation of both the strain gage bonding areas and the strain gage leadwire routing bonding paths were utilized for these tests.

Instead of using the 400-grit silicon-carbide paper, which is normally used to abrade the strain gage areas, a 320-grit silicon-carbide paper along with the proper chemicals was utilized. This was performed to provide a slightly thicker glue line under the strain gages to enhance the survivability of the gages at the higher (g) airgun test levels.

Also, for the surface preparation of the routing paths over which the enamel-coated #34 American Wire Gauge (AWG) leadwires would be bonded/encapsulated, a 220-grit silicon-carbide paper was utilized in lieu of the normal 320 grit, along with the proper chemicals.

Utilizing a two-part strain gage adhesive, the four uniaxial strain gages were bonded to the cantilever beam (the test article). The strain gages were bonded at an ambient temperature of +71 °F, for a 16-hr duration. Strain gages were positioned vertically (at maximum ue response orientation) on the cantilever beam, at a position that was 1/8 in above the juncture of the cantilever beam to the OBR housing end cap. Horizontally, they were near the center line of the OBR housing end cap.

5. Preparing Surfaces for the Bonding of the Teflon* Accelerometer Cables

The areas over which the Teflon fluoropolymer-coated accelerometer cables would be bonded were prepared by the utilization of 220-grit silicon-carbide paper and the proper chemicals. After surface preparation, the cables were routed in a large strain relief pattern. Using small pieces of a low-mastic masking tape, the accelerometer cables were taped into place. The tape not only kept the cables in the desired pattern, but also aided in the bonding of the accelerometer cables over the routing paths with a two-part (5-min set time) epoxy.

6. Fabricating of Strain Gage Leadwires, and Providing Protection for Them

For each of the four strain gage locations, three enamel-coated #34 AWG strain gage leadwires were twisted together utilizing a “manual” drill. This was performed to minimize

* Teflon is a registered trademark of E. I. du Pont de Nemours and Company.

electromagnetic fields from inducing undesired “noise” voltages into the measurand circuitry.

Protection for the fragile preformed strain gage leadwires was performed by the application of a mixture of nitrile rubber and methyl ethyl ketone (MEK) to the formed strain gage leadwires.

7. Utilizing Flexible Strain Reliefs for Strain Gage Leadwire Protection

To provide protection to those fragile strain gage leadwires that are required to make a transition by 90° to another surface, a flexible strain relief was utilized. The flexible strain relief consists of a small piece of silicone tubing placed under the strain gage leadwires, at the point where the 90° transition of the leadwires is desired. Then, a low-mastic masking tape is used to temporarily hold the leadwires to the test article’s surface during the application of a protective barrier to the area of the flexible strain relief.

Due to the “capillary attraction” that occurs during the application of the two-part strain gage adhesive over the enamel coated #34 AWG leadwires, a protective barrier must be put in place over the flexible strain relief. Then, it is required that this protective barrier be allowed to be “fully cured” prior to the encapsulation of the strain gage leadwires.

The first part of the protective barrier is the application of a thin coat of room-temperature vulcanizing (RTV) primer over the area of the flexible strain relief. This primer is to be allowed to air dry at ambient temperature for a period of 10 min. Next, a thin coat of (self-leveling) RTV sealant is placed over the vicinity of the flexible strain relief. It is imperative that this RTV sealant is cured at a 50% relative humidity and at a minimum temperature of 75 °F (+24 °C). The duration of the curing is 24 hr per each 0.020 in of sealant thickness that one applies.

What cannot be stressed enough is that if a complete cure is not allowed of the RTV sealant, then capillary attraction will occur as the strain gage adhesive will pass over the strain gage leadwires and “under” the uncured RTV sealant. The result being, that instead of having a flexible strain relief to survive structural yielding, a solid adhesive rock will be cured at the desired point of the flexible strain relief. Thus, as a physical displacement occurs, the leadwires may break and thus lose data from the strain gage(s).

8. Location of Four Flexible Strain Reliefs for Strain Gage Leadwire Protection

In figure 2 (first strain relief), notice that to the left of the epoxy-filled hole in the OBR housing end cap (containing the wires), there exists a flexible strain relief as the wires transition from the

epoxy hole onto the OBR housing end cap. Also, in figure 2 (second strain relief), close investigation on the left side will reveal a flexible strain relief just as the strain gage leadwires transitioned vertically from the OBR end cap onto the cantilever beam, en route to the strain gages. The third strain relief is not visible in figure 2 because it is located on the hidden side of the cantilever beam. It is located in the same position as the second strain relief, i.e., just as the strain gage leadwires transitioned vertically from the OBR end cap and onto the cantilever beam en route to the hidden strain gages. The fourth strain relief is shown in figure 3; it is located on the bottom side of the OBR housing end cap, below and to the left of the epoxyed hole. This flexible strain relief protects the strain gage leadwires as they transition from the inside bottom of the OBR housing end cap and through the epoxy hole in route to the strain gages.

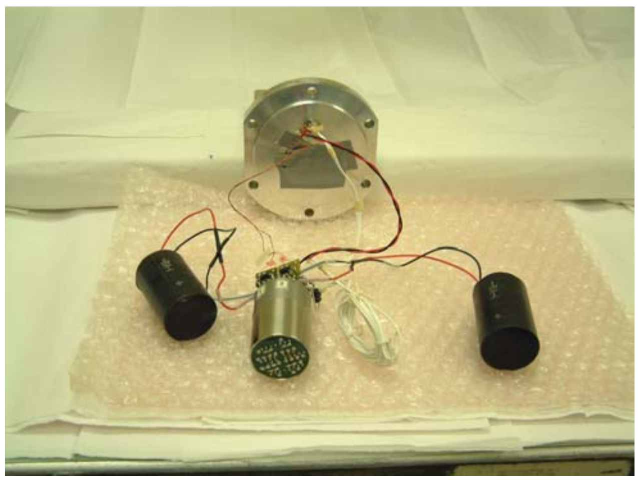

Figure 3. The integration of the OBR with the test article.

9. Encapsulation of the Strain Gage Leadwires

After the "total curing" of the RTV sealant over the flexible strain reliefs has occurred, use a strain gage low-mastic cellophane tape to limit the width of the encapsulation of the strain gage leadwires with the two-part strain gage adhesive.

10. OBR Configuration and Calibration

For each of the four channels of the OBR, several calculations are made for the specific test configuration. Then, precision 1% film range gain resistors are installed in each of the four channel analog input printed wiring boards (PWB). From the calculations, the proper precision resistor sets each channel for the range of gain for the sensor attached to each channel. Configuration of each channel for the specific tests is accomplished by the attachment of the

proper type of input sensor PWB to each of the four channels' analog input (PWB). Each of the sensors' leadwires or cables is soldered to the appropriate input sensor (PWB) and then is encapsulated with a two-part 5-min set time epoxy, to provide protection during the high g-shock levels of testing. From the calculations, the desired "zero" base line measurand response is achieved by the proper selection and soldering of the offset/bias 1% precision resistor to each of the four channel input sensors (PWB).

To conserve the OBR batteries, an external low noise power supply is utilized during the calibration of the OBR. After calibrating each of the four OBR channels, new calculations are made using each channel's parameters. Both shock-hardened batteries are soldered to the OBR power leads, the OBR is brought up to full power level, and the reserve battery level is verified, prior to the integration of the OBR with the test article.

11. The Integration of the OBR With the Test Article

In figure 3, "the circular" OBR PWB that is in the foreground, is that part of the OBR which at post-test is mated with an interface box to transfer acceleration and microstrain test data stored in the memory of the OBR to a PC containing the necessary software for the processing of the acquired test data.

Prior to inserting the OBR into the OBR housing and the glass beads, one must form a triad with the OBR and the two shock-hardened batteries. This is accomplished by using two wide rubber bands to bring the two batteries into contact with the OBR. The result is a triad in which each of the three components are at one angle of an equilateral triangle.

On one side, in the space between one of the batteries and the OBR, the accelerometer leads and one set of battery leads are stored under the two rubber bands. On a second side, in the space between the second battery and the OBR, the second set of battery leads is stored under the two rubber bands.

12. Packaging of the OBR Assembly Into the OBR Housing With Glass Beads

Mechanical isolation is provided to the OBR assembly through the usage of glass beads having a 60–100 sieve size. The glass beads contain no free silica.

On the inside bottom of the OBR housing, a 3/4-in-thick base of glass beads is packed into place, to provide mechanical isolation for the OBR as the OBR housing impacts with the mitigator during the airgun test. This 3/4-in base of glass beads is packed in place by tapping the side of the OBR housing with a sand-filled plastic mallet until the glass beads are packed tightly in the

inside bottom of the OBR housing. After the glass beads are tightly packed into place, the OBR assembly is then carefully inserted into the OBR housing.

After the OBR assembly is placed into the OBR housing, a check is made to ensure that neither the OBR nor the batteries are contacting any inside surface of the OBR housing. Then, glass beads are poured into the OBR housing until the glass beads are at a level of about one-third of the depth of the OBR housing. Using a plastic sand-filled mallet, the outside surfaces of the OBR housing are continually lightly tapped. As the process continues, one notes no further drop in the level of the glass beads inside of the OBR housing as the glass beads are packed tightly.

Figure 4, at the top left photograph, shows the beginning of the process of continually filling and packing in stages of the OBR housing with the glass beads.

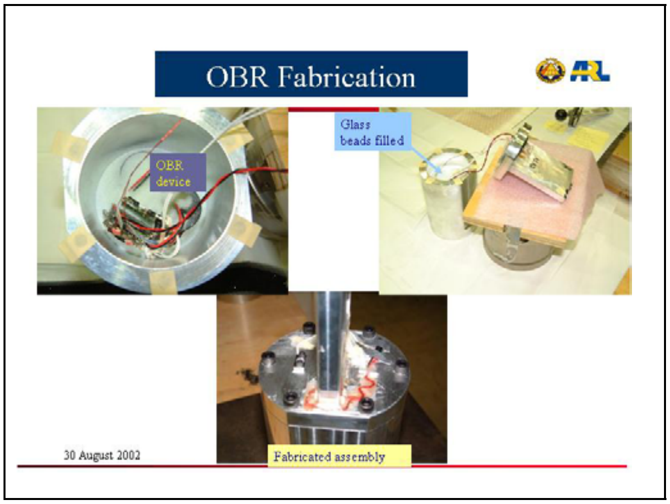

Figure 4. Packaging of the OBR assembly into the OBR housing with glass beads.

As shown in figure 4, at the top right photograph, when the level of the glass beads inside the OBR housing has been tightly packed to about 80% of the inside depth of the OBR housing, then all the cables and leadwires are carefully placed inside the OBR housing, and the OBR housing end cap is bolted to the OBR housing.

Now, the process of filling and packing of the remaining 20% of the interior of the OBR housing with glass beads is accomplished through the fill hole in the OBR end cap. The fill hole is the same hole through which all the accelerometer leads and strain gage leadwires pass through the OBR end cap. When the point is reached where no more glass beads can be packed into the OBR housing, the fill hole is sealed with epoxy.

At this point, the OBR assembly is given to the airgun section for testing. At post-test, the acceleration and microstrain data stored in the memory of the OBR is retrieved and processed. Analysis of the processed data is performed by Mr. Abrahamian (figures 5 and 6).

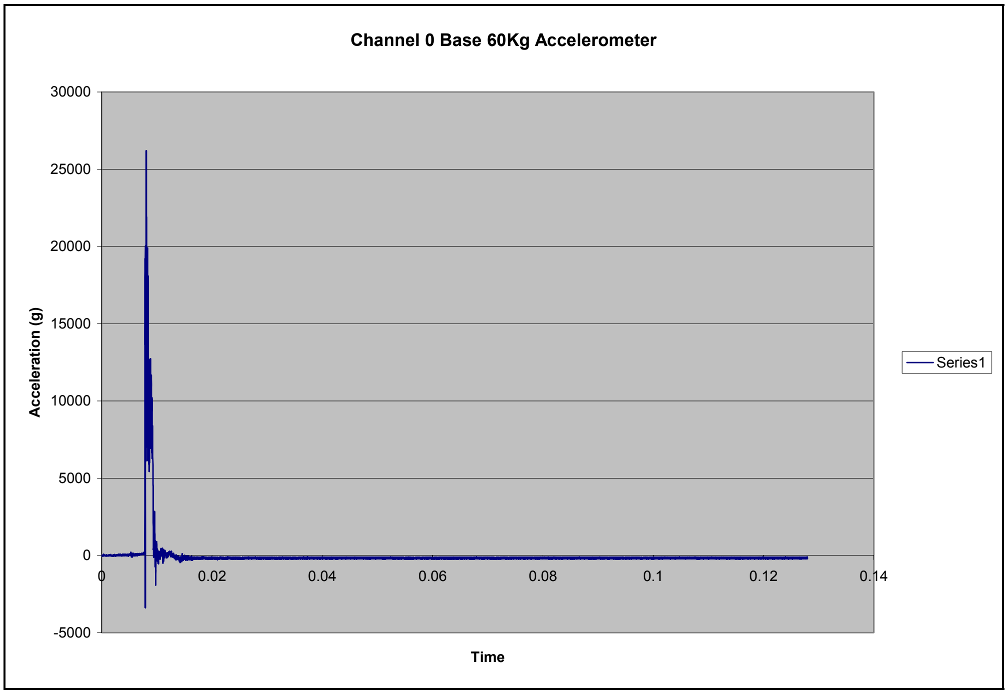

Figure 5. Acceleration data plot from OBR during airgun test no. 3. (Location of accelerometer on top side of the end cap.)

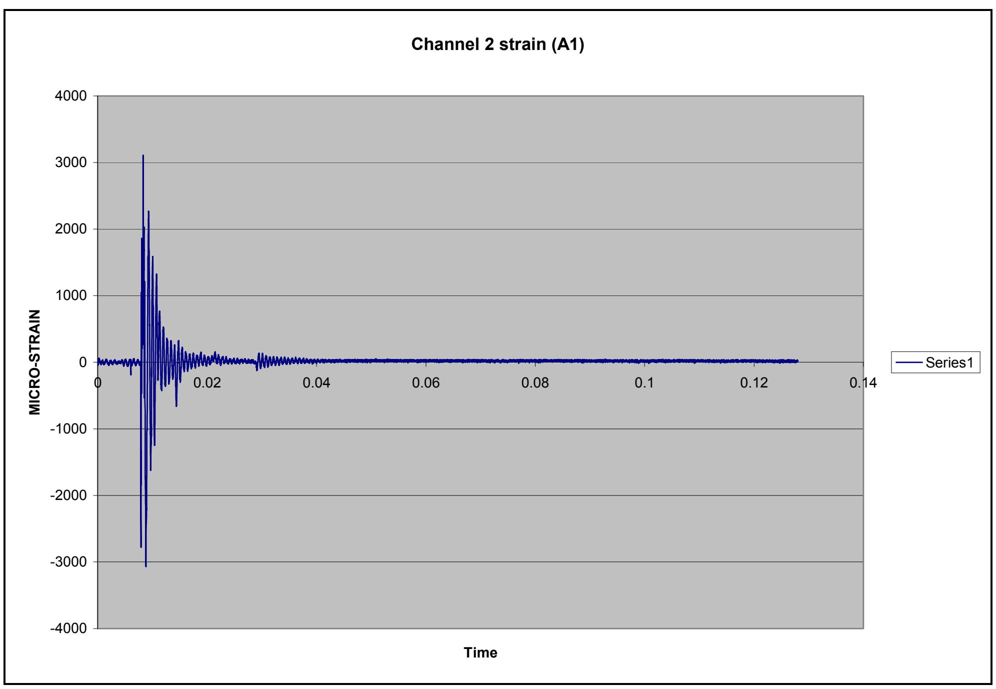

Figure 6. Microstrain data plot from OBR during airgun test no. 3.

13. Conclusion

During the three high kilogram airgun tests, an enhanced survivability for the fragile twisted enamel coated #34 AWG strain gage leadwires was obtained, through the proper preparation and implementation of the flexible strain reliefs as is described in the text.

At post-test for each of the three airgun tests, a physical inspection of the strain gage leadwires and flexible strain reliefs was performed. The results of which showed all strain gage leadwires remained in tact, especially the flexible strain reliefs.

The author developed this technique of utilizing a flexible 1/16-in outside diameter silicone cord, with proper preparation as a flexible strain relief during a prior project.

In the prior project, the author was given the task of instrumenting lethal mechanism cases and electronic module housings with strain gages in a 155-mm projectile for live gunfire. The instrumentation was subjected to not only the normal setback and set-forward forces, but also to a large centrifugal force, since this was a rifled round. During the course of the strain gage instrumentation process, through risk mitigations, the utilization of the flexible strain reliefs for the strain gage leadwires was developed along with the preparation and protective barrier system.

During the live gun fire at Yuma Proving Ground, the strain gage instrumented round obtained in-bore data. At post-test, the strain gage instrumented hardware was given a close visual inspection. The strain gages and their associated leadwires remained in tact during the live gunfire test.

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